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1 Snatch Trajectory of Elite Level Girevoy (Kettlebell) Sport Athletes and its Implications
2 to Strength and Conditioning Coaching

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Snatch Trajectory of Elite Level Girevoy (Kettlebell) Sport Athletes and its Implications
to Strength and Conditioning Coaching

Abstract

Girevoy sport (GS) has developed only recently in the West, resulting in a paucity of English scientific literature available. The aim was to document kettlebell trajectory of GS athletes performing the kettlebell snatch. Four elite GS athletes (age = 29-47 years, body mass = 68.3-108.1 kg, height 1.72-1.89 m) completed one set of 16 repetitions with a 32.1 kg kettlebell. Trajectory was captured with the VICON motion analysis system (250 Hz) and analysed with VICON Nexus (1.7.1). The kettlebell followed a 'C' shape trajectory in the sagittal plane. Mean peak velocity in the upwards phase was $4.03 \pm 0.20 \text{ m s}^{-1}$, compared to $3.70 \pm 0.30 \text{ m s}^{-1}$ during the downwards phase, and mean radial error across the sagittal and frontal planes was $0.022 \pm 0.006 \text{ m}$. Low error in the movement suggests consistent trajectory is important to reduce extraneous movement and improve efficiency. While the kettlebell snatch and swing both require large anterior-posterior motion, the snatch requires the kettlebell to be held stationary overhead. Therefore, a different coaching application is required to that of a barbell snatch.

Key Words: Kettlebell, Resistance Training, Snatch

1 INTRODUCTION

2 Kettlebell exercise was initially seen at the end of the 17th century in Russia, where
3 strongmen used 16 kg, 32 kg and 48 kg kettlebells to demonstrate feats of strength at
4 fairs, festivals and circuses [1, 2]. The first kettlebell sport, or 'Girevoy sport' (GS)
5 competition was held in 1948 and fourteen years later, GS was included into the
6 national sports of Russia [1]. Over the past ten years, kettlebell training has become
7 increasingly popular as a form of resistance training for athletes and members of the
8 general population, coinciding with increased participation in GS competition. Whilst the
9 versatility of kettlebells allows the performance of many exercises; swings, jerks, clean
10 and jerks, and snatches are some of the most commonly performed kettlebell
11 movements.

12 The snatch is typically performed with a barbell in Olympic weightlifting events, although
13 dumbbell and kettlebell versions are becoming more popular. The kettlebell snatch is
14 performed in a biathlon or as a standalone event in GS competitions. The competition
15 takes place on a weightlifting platform and has a time limit of ten minutes per set. The
16 biathlon is scored as the total number of repetitions performed from two exercises: the
17 jerk followed by the snatch, each of ten minutes duration, with at least an hour between
18 exercises. The snatch is performed with one hand change permitted per set and is
19 considered the most technical event in GS [1]. Elite individuals perform the kettlebell
20 snatch with a 32 kg kettlebell during the ten minute competition, with the current
21 absolute world record standing at 238 snatches.

22

1 It has been suggested that kettlebell training is a useful mode of training to improve
2 aerobic fitness [3-5], vertical jump [6-9] and back squat performance [7, 9]. Previous
3 research utilising a 32 kg 2-handed kettlebell swing demonstrated similar power outputs
4 and a larger impulse, compared to the jump squat with 40% 1RM [8]. A training study
5 comparing the chronic effects of kettlebell swings and jump squats was reported to
6 significantly improve vertical jump and back squat 1RM. However, the kettlebell group
7 had a smaller improvement in the vertical jump, yet larger improvement in back squat
8 performance [7]. Of the two interventions that investigated the effects of kettlebell
9 training on the cardiorespiratory system, only one found improvements. It is possible
10 that the reason for the lack of improvement was due to the low training dosage of 10-15
11 minutes three times a week with 70% adherence [10]. In contrast, 30-45 minutes of
12 training twice a week, using a combination of kettlebell exercises including the snatch,
13 was found to improve VO₂peak by 13.8% during a progressive kettlebell snatch set [5].

14
15 Generally, only qualitative descriptions of the kettlebell snatch during elite performance
16 are available. The International Kettlebell Sport & Fitness Academy has described the
17 snatch as comprising six components [11]. As seen in Figure 1, the start and finish are
18 referred to as “fixation”. This is where the kettlebell is locked out overhead. The three
19 components of the downwards phase include: the drop, re-gripping, and back swing,
20 while the upwards phase involves the forward swing, acceleration pull, and hand
21 insertion (refer to Figure 1).

1 Figure 1 about here

2

3 Figure 2 about here

4

5 Figure 2, point 1 represents fixation. In this position, the handle of the kettlebell rests
6 diagonally across the palm and the ball rests on the back of the wrist and forearm [11].
7 The drop is initiated by a counter movement of the torso away from the kettlebell. At
8 approximately the same time, the shoulder begins to extend, and the elbow supinates
9 and flexes [1, 11]. Between the 'drop' and the 'back swing' the handle is repositioned
10 (re-gripped) from the palm to the fingers [11]. This portion of the downwards trajectory is
11 indicated at approximately Figure 2, point 2. At the start of the back swing the knees are
12 slightly flexed and the torso remains upright, until the kettlebell passes between the
13 legs, whereby the hips flex and the knees extend (finishing at Figure 2, point 3). The
14 forwards swing phase consists of the kettlebell moving forward between the legs via hip
15 extension and knee flexion. The acceleration pull (approximately Figure 2, point 4)
16 begins as the kettlebell passes the knees. This is the most powerful motion in the
17 snatch, and involves knee and hip extension, ipsilateral torso rotation and elbow flexion
18 [11]. It ends when the kettlebell is once again re-gripped (hand insertion). During the
19 hand insertion phase, the elbow is extended and the torso rotates contralaterally [11].
20 This rotates the kettlebell, moving the handle from the fingers to the palm, bringing it
21 into contact with the wrist and forearm [11]. The kettlebell comes to rest in the overhead
22 position whilst in fixation, and the process is then repeated (see Figure 1). It has been

suggested that in the upwards and downwards phases the kettlebell follows somewhat different trajectories [1]. To our knowledge, only one study has examined the technique of the kettlebell snatch [12], reporting that novice participants extend the hips, knees and ankles simultaneously, and swing the kettlebell through the sagittal plane. The kettlebell snatch was further described to have rapid muscle activation-relaxation cycles, producing relatively large posterior shear forces on the spine [12].

This proposed trajectory of the snatch performed with a kettlebell appears quite different to that of the snatch performed with barbells or dumbbells. The barbell snatch and power snatch has been shown to follow an 'S' or reverse 'S' shaped trajectory, characterised by an initial small displacement of the barbell rearwards, then forwards and rearwards again [13, 14]. This type of trajectory allows the weightlifter to move through the first pull and transition phase, and to adopt the power position prior to the second pull. The power position may allow for the generation of very large power outputs during the second pull [15]. Elite weightlifters were found to have an anterior posterior range of -0.096 ± 0.07 m during successful barbell snatch attempts. In contrast, the trajectory of a dumbbell power snatch is displaced forwards then rearwards [16].

During competition, the barbell snatch is performed with a bilateral grip for one maximal repetition. Conversely, the kettlebell snatch is performed unilaterally and traditionally utilises multiple repetitions in competitions. The duration and technique used in the upwards and downwards phases may both be of importance. Additionally, the kettlebells displaced centre of mass sits below the wrist. This makes it much harder to safely fail a single maximal lift of a kettlebell snatch, compared to that of a barbell or dumbbell snatch. This may suggest the kettlebell snatch is better suited to higher

1 repetitions than the barbell snatch and as such may be a better tool for increasing
2 energy expenditure and developing aerobic and anaerobic conditioning.

3
4 In comparison to the barbell snatch, the unilateral nature of the kettlebell snatch allows
5 for greater degrees of freedom, which may result in a larger choice of techniques.
6 However, the unique shape of the kettlebell may necessitate a modified approach to
7 training and technique, in contrast to that of a barbell. The material and body of
8 knowledge available to coaches regarding kettlebell exercises for training purposes is
9 limited. The present study aimed to investigate the kettlebell trajectory of elite kettlebell
10 lifters during the snatch. This information is especially important for coaches and
11 strength and conditioning specialists looking to prescribe higher repetition snatch
12 movements for their athletes. As a training tool, the kettlebell snatch may be better
13 suited to higher repetitions. Comparatively, this may require different applications to that
14 of the barbell snatch, traditionally utilising one repetition in competition.

16 **METHOD**

17 **Testing Procedures**

18 Four elite participants performed 16 repetitions over one minute with one 32 kg
19 kettlebell. Repetitions 2-16 were compared to help determine the variation in the
20 trajectory as these repetitions all had a downward phase preceding the upward.
21 Kettlebell trajectory was captured with the VICON Motion Analysis System (250 Hz) and

analysed with VICON Nexus (1.7.1). The cadence of 16 repetitions per minute was selected based on similar cadences sustained during either training or competition.

Participants

Four elite kettlebell sport athletes (originating in Russia or Kyrgyzstan), who had all won at least one world championship in biathlon (jerk and snatch) and/or held past or current world records in the snatch, were recruited. In their most recent competition, which occurred within 12 months of data collection, all lifters performed between 80-100% of the current world record number of lifts with a 32kg kettlebell for their respective weight categories. All participants held the rank of 'Master of Sport International Class' or 'Honored Master of Sport', (as issued by the Ministry of Sports of Russia, or the USSR State Committee for Physical Culture and Sport). The four participants had the following characteristics: age = 29-47 yr, body mass = 68.3-108.1 kg, and height = 1.72-1.89 m. This study was approved by the Institutional Review Board. Informed consent was given, in the presence of a translator if required.

Procedures

Six VICON infrared cameras were placed around a weightlifting platform in a position to capture three dimensional motion of the kettlebell during the snatch. The infrared cameras captured the movement of reflective markers placed on the kettlebell. The system was calibrated dynamically by waving an L-wand with five reflective markers in the area that the kettlebell would pass through, in accordance to the manufacturer's instructions. This was repeated until all cameras had an RMS error under 0.2% [17]. The point of origin was then set in the middle of the platform, to calibrate the cameras

positions. A professional-grade kettlebell (Iron Edge, Australia), with a mass of 32.1 kg was used as its dimensions are the standard requirement for kettlebell sport. Two markers (14 mm x 12.5 mm in diameter) were placed on the kettlebell at the base of each handle to avoid contact with the athlete and to ensure consistent position.

Participants were required to perform a warm-up they would typically perform prior to performing the kettlebell snatch. Chalk, sand paper and a spray bottle were provided to ensure that the handle was prepared to their individual lifting requirements. After the marker set had been placed, each lifter stood on a platform and performed one set of snatches for 16 repetitions over 1 minute with their self-selected hand. This pace was selected as it was the competition pace for one or more of the athletes, was attainable by novice and intermediate athletes (albeit with lighter loads), and commonly performed in training and competition. An analogue clock was placed in view to allow consistent pace.

Kettlebell trajectory was subsequently determined by attaining the midpoint of the two markers. After each trial had been performed the markers were manually labelled using VICON Nexus software. A frame-by-frame review of each trial was undertaken to ensure there was minimal error caused by unlabelled markers. After this review took place a Woltering spline filter was applied to fill any gaps (less than 20 frames) in the trajectories [18]. These gaps in the trajectories were calculated by the markers past trajectory, velocity and acceleration.

Time displacement data was used to determine the trajectory and velocity in three dimensions of motion. For ease of interpretation resultant velocity was used. Four points of each repetition of the kettlebell trajectory were analysed: 1) fixation; 2)

midpoint of the downwards phase; 3) end of the back swing; and 4) midpoint of the upwards phase (see Figure 2).

These four points were identified the moment the kettlebells trajectory changed from an anterior to posterior direction, or vice versa. The mean position from all 15 repetitions at these four points was the goal position. These four points were used as a reference to determine the error in one and two dimensions. The absolute error (AE, including vertical error, anterior-posterior error and medio-lateral error) illustrated the distance in metres from the goal in one dimension [19]. The radial error (RE, including sagittal plane error and frontal plane error) signified the distance in metres from the goal in two dimensions [19]. The RE was calculated by using the following formula:

Equation 1. (RE in the sagittal plane = $\sqrt{(\text{Vertical error})^2 + (\text{Anterior Posterior error})^2}$)

Equation 2. (RE in the frontal plane = $\sqrt{(\text{Vertical error})^2 + (\text{Medio - Lateral error})^2}$)

The anterior-posterior (AP), medio-lateral (ML) and vertical displacements were calculated from the end of the back swing to the midpoint of the trajectory for AP and ML, and to fixation for the vertical displacement range. Comparisons in the lifters' trajectories were also made using an anterior-posterior to vertical ratio (APV), and medio-lateral to vertical (MLV) ratio. The end of the back swing to fixation mean displacement range was used to determine the vertical portions of the ratios.

Statistical Analyses

Data has been presented as means and standard deviations unless stated otherwise. Descriptive statistics were used to determine the amount of kettlebell AP, ML motion and variation for each lifter. Effect size (ES) and paired t-tests with two tails were used to compare the midpoint of the upwards and downwards phases for each repetition. The magnitude of the effect was considered trivial ES <0.2, small ES 0.2-0.6, moderate 0.6-1.2, large ES 1.2-2.0, very large ES 2.0-4.0 and extremely large ES > 4.0 [20]. The AE and RE for repetitions 2-16 were calculated. The first repetition was ignored because it started from the ground and not in fixation. The variation was determined at the same four points, listed above. AE was calculated in AP, ML and vertical planes of motion. RE was calculated in the sagittal and frontal planes.

RESULTS

Trajectory

In the sagittal plane, the trajectory of the kettlebell snatch followed a C-path for all participants through the upwards and downwards phases (Figure 3). Figure 3 illustrates the kettlebell sagittal plane trajectory for the four subjects, whilst Figure 4 represents the kettlebell trajectory in the frontal plane of motion.

Figure 3 about here

Figure 4 about here

1

2 **Ratios and displacement**

3 Table 1 illustrates the kettlebell displacement ranges and ratios. The APV and MLV
4 ratios indicate that the C-path followed a larger radius during the upwards than
5 downwards phase for all participants. Participants B, C, and D had a relatively smaller
6 MLV ratio ranging from 0.05-0.13 for both phases compared to participant A, who had a
7 relatively larger MLV ratio of 0.31 ± 0.01 and 0.26 ± 0.02 for the upwards and
8 downwards phases, respectively.

9 Table 1 about here

10

11 Table 2 shows the AP, ML and vertical displacement ranges between the upwards and
12 downwards phases. The downwards phase represents the smallest arc, compared to
13 the upwards phase. The range between the upwards and downwards phases was
14 largest in the AP, compared to the ML differences in all lifters.

15

16 Table 2 about here

17

18 **Velocity**

19 Participants' peak kettlebell resultant velocity ranged from moderate to extremely large
20 ES difference, whereby the upwards phase was faster than the downwards phase for all

1 lifters, except lifter A (see Table 3). Figure 5 shows the typical velocity of the kettlebell
2 as it moved from the downwards phase to the upwards phase. The two peaks in velocity
3 occurred approximately in the re-gripping phase and during the acceleration pull. The
4 two noted times in which velocity reached zero were at fixation, and momentarily
5 between the back and forwards swing.

6
7 Figure 5 about here

8
9 Table 3 about here

10 11 **Movement Variability**

12 Table 3 shows AE, RE and displacement range for the three dimensions for each
13 participant. The AE and the RE indicate that the kettlebell trajectory was highly
14 consistent at each of the four points for all four participants.

15
16 Table 4 about here

17 18 **DISCUSSION**

1 Three dimensional motion analysis was used in this study to document kettlebell snatch
2 kinematics performed by elite kettlebell athletes. The main findings were that despite
3 some differences between the four athletes, significant commonalities emerged: 1)
4 there was a 'C' shape trajectory during the downwards and upwards phases of the
5 snatch; 2) the 'C' shape followed a narrower trajectory during the downwards phase;
6 and 3) the resultant velocity time graph resembled an 'M' shape.

7 One marked similarity was the narrow 'C' shape trajectory on the way down and a wider
8 'C' shape on the way up. The smaller radius on the way down may be due to several
9 reasons. During the initiation of the downwards phase it was noticed that all athletes
10 moved their bodies away from the kettlebell. This allowed for the kettlebell to fall as
11 closely as possible to the base of support. Following the initial counter movement the
12 athlete flexes and supinates the elbow [1, 11]. The supination of the elbow may help to
13 reduce the movement of the kettlebell through the AP plane and minimise grip stress
14 (and subsequent fatigue) during the transition into the re-gripping phase. The flexion of
15 the elbow may also minimise the AP movement of the kettlebell, thereby again placing
16 the kettlebell as close to the base of support as possible. The large radius from the
17 forwards swing to the start of the acceleration pull may help to minimise the centripetal
18 force acting on the grip. Following the acceleration pull, the hand insertion phase guides
19 the kettlebell onto the back of the wrist. The grip must relax during this phase to help
20 facilitate a smooth transition into fixation. Reducing the stress on the grip may help to
21 prolong performance as anecdotally grip endurance is considered the weakest link in
22 elite GS athletes. Paying particular attention to the hand insertion will also help to
23 reduce the potential for the kettlebell to have heavy contact upon the forearm, and

1 therefore reduce the risk of musculoskeletal injury to the distal forearm. Strength and
2 conditioning coaches need to be aware of this before their athletes progress the
3 kettlebell snatch.

4 Movement was remarkably consistent for all athletes in the frontal and sagittal planes.

5 This is most likely to minimise energy expenditure and therefore fatigue over the ten
6 minute event. The most consistent of the four points was the fixation phase which had a
7 RE range of 0.008 ± 0.006 m and 0.023 ± 0.016 m, in both sagittal and frontal planes.

8 This would suggest that a consistent fixation phase is of the upmost importance. Low
9 endpoint variability is most useful to ensure that the mass of the kettlebell is over the
10 shoulder in all three planes. If this was not the case, greater energy and time would be
11 used fixating or locking out the kettlebell overhead. Within the limitations of the research
12 it can be concluded that elite kettlebell sport athletes maintain a consistent trajectory,
13 particularly at some of the key positions of the movement. Maintaining consistent
14 fixation may be key in increasing the reproducibility of the trajectory as it marks the start
15 and finish of the lift. The trajectory of the kettlebell for athletes A and C followed a
16 similar path during both the downwards and upwards phases in the sagittal plane, whilst
17 the vertical midpoints were at a relatively similar level for lifters A and C (0.022 ± 0.015
18 m and 0.034 ± 0.020 m trajectory difference, respectively). In contrast, the trajectory for
19 athletes B and D were visibly separated and the vertical midpoint of the 'C' shape
20 occurred in different vertical positions in the upwards and downwards phases ($0.062 \pm$
21 0.030 m and 0.094 ± 0.028 m, respectively) (Figure 3). These differences in trajectory
22 could be explained by: 1) greater trunk rotation in the acceleration pull phase; 2) the
23 degree of plantar flexion in the upwards or downwards phase; 3) a larger shift

backwards during the downwards phase; 4) the position of the upper extremity; and 5) possibly anthropometrical differences. Unfortunately, the present study only assessed the motion of the kettlebell, however, future studies may be useful to better describe the relationship between the kettlebell and lifters kinematics. Potentially, technique may differ over the course of the ten minutes due to fatigue or changes in cadence, however, these differences were beyond the scope of the present study.

Based on the kettlebell kinematics, it appears that different strategies were used to prolong performance in the different lifters. Lifter A displayed the largest MLV range in the upwards and downwards phases, which may produce fatigue in the contralateral musculature to a greater extent. In novice athletes, the mean activation of the lower erector spinae performing the kettlebell snatch with a sagittal plane trajectory was 54.2 ± 18.3 and 61.3 ± 16.3 % MVC for the ipsilateral and contralateral sides, respectively [12]. Lifter A may increase the demands of the contralateral musculature further by increasing the ML moment arm (which is reflected in his MLV ratio). This may increase the requirements of the torso to resist or control lateral flexion to a greater extent, in an effort to offset fatigue for the last five minutes. In doing so, they may possibly spare the ipsilateral side for subsequent effort following the hand switch as it will become the contralateral side at the five minute mark. Thus, having a larger MLV ratio trajectory may be a strategy to help spread the loading across different muscle groups during the left and right hand efforts. This strategy may be particularly useful during biathlon, as athletes must perform the jerk, which predominantly takes place in the sagittal plane one or two hours prior to the snatch, and may still be experiencing fatigue from this

1 effort [3, 4]. Lifters B, C and D had much smaller MLV ratios compared to lifter A. The
2 dominant AP trajectory in lifters B, C and D suggests that their strategy requires
3 relatively symmetrical loading, resulting in less effort by a single muscle group, thus
4 prolonging performance. A sagittal plane dominant trajectory similar to lifters B, C and D
5 may offer strength and conditioning coaches a technique with the greatest ease of
6 application. Conversely, lifter A's style may be useful in a GS setting, however it would
7 require a coach to monitor both sagittal and frontal planes of motion, with respect to the
8 kettlebell trajectory.

9 As previously stated, upward phase horizontal displacement of the kettlebell was
10 greater than the downward phase equivalent for all lifters, perhaps to reduce the
11 centripetal load on the fingers. Increasing kettlebell velocity may further increase the
12 centripetal stress on the fingers. Two peaks in velocity between the upwards and
13 downwards phases were observed across all lifters. The first peak occurred
14 approximately in the re-gripping phase, and the second generally in the acceleration pull
15 phase. Lifters B, C and D had slower peak velocities in the downwards phase, whereas
16 lifter A's peak velocity was greatest during the downwards phase. Reducing the velocity
17 on the downwards phase could help to reduce stress placed on the finger flexors,
18 however it could also increase the time needed to perform each repetition, which may
19 be counter-productive to the objective of the sport which is to perform as many
20 repetitions as possible in 10 minutes. Strength and conditioning coaches should be
21 aware that in addition to the obvious effect of altering the kettlebell mass, different
22 cadences and/or anthropometric factors may result in different kettlebell velocities.
23 Therefore, an increase in cadence may result in greater velocity in the downwards

1 phase and a faster eccentric phase. This increase in repetition velocity may result in
2 greater grip and systemic fatigue, which may only be sustainable over shorter time
3 periods.

4 **Conclusion**

5 The kettlebell snatch trajectory of elite GS athletes follows a 'C' shaped path. There
6 were two differently shaped 'C' trajectories, one with a smaller radius on the downwards
7 phase, and the other a larger during the upwards phase. Kettlebell displacement
8 occurred predominantly in the sagittal plane, although varying and relatively smaller
9 amounts of horizontal displacement were recorded in the frontal plane. Within the
10 upwards and downwards phases, low movement variability appears an important factor,
11 particularly in the overhead fixation position. With the kettlebells potential large degrees
12 of freedom, individual athlete style may affect their trajectories.

13 Additionally, there were two peaks in velocity which occurred in the upwards and
14 downwards phases. This technique easily facilitates multiple repetitions due to its
15 cyclical upwards and downwards phases. This research has shown that the kettlebell
16 snatch can be performed with consistent kettlebell trajectories and velocities for 15
17 repetitions by elite GS athletes in a relatively unfatigued state.

18 **Practical application**

19 The kettlebell snatch may be a useful option as an alternative to high repetitions of the
20 barbell snatch, as it can be performed consistently. This may be particularly useful for
21 strength and conditioning coaches, wishing to program an explosive total body
22 movement such as the snatch for higher repetitions. Additionally, the unilateral and

1 swinging nature of the kettlebell may provide a unique stimulus. Programming a snatch
2 for higher repetitions may increase the metabolic and grip demands [5]. These
3 components may also be important factors in sports that require a combination of
4 strength and endurance qualities. Grip strength is an important component of Judo
5 competition [21]. Grappling sports such as Judo, freestyle and Greco-Roman wrestling
6 typically involve tournament formats and a progressive increase in fatigue and grip
7 strength loss occurs with each bout during these tournaments [22-25]. The kettlebell
8 snatch may have potential application in these sports, as it may promote increased
9 levels of local muscular endurance. In contrast, the barbell snatch has been well
10 researched and is an effective stimulus for power adaptations [15]. Its trajectory follows
11 an 'S' shape which is predominantly vertical, allowing for positions which maximise
12 power output. Therefore, the barbell snatch would be most appropriately programmed
13 for lower repetitions, in contrast to the kettlebell snatch, which may be better suited to
14 higher repetitions. The kettlebell snatch has a cyclical component, as it contains an
15 upwards and downwards phase. Following a 'C' trajectory will help to prolong
16 performance and in turn training volume, which may allow for greater training outcomes.
17 Problems may arise if a lifter attempted to apply an 'S' trajectory to the kettlebell, which
18 may not be appropriate or attainable, and may cause the hand insertion and fixation
19 phases to occur too closely together (when the arm is vertical). This may lead to greater
20 impact upon the forearm, thus increasing the risk of injury. Evidently, kettlebell snatch
21 technique should not be taught in the same manner as the barbell snatch.

22 23 **Limitations**

1 The small sample size recruited is the major limitation within this research, however the
2 athletes involved are all elite within GS, making them of particular interest. Due to time
3 constraints and international travel stress, the lifters were unable to perform 10 minute
4 sets at a competition pace for this study. This would have offered an insight into their
5 trajectories in a fatigued state. A total of 16 repetitions were studied over one minute.
6 The number of repetitions performed was at competition pace for the two lighter lifters.
7 However, this was below competition pace for the two heavier lifters.

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FIGURES

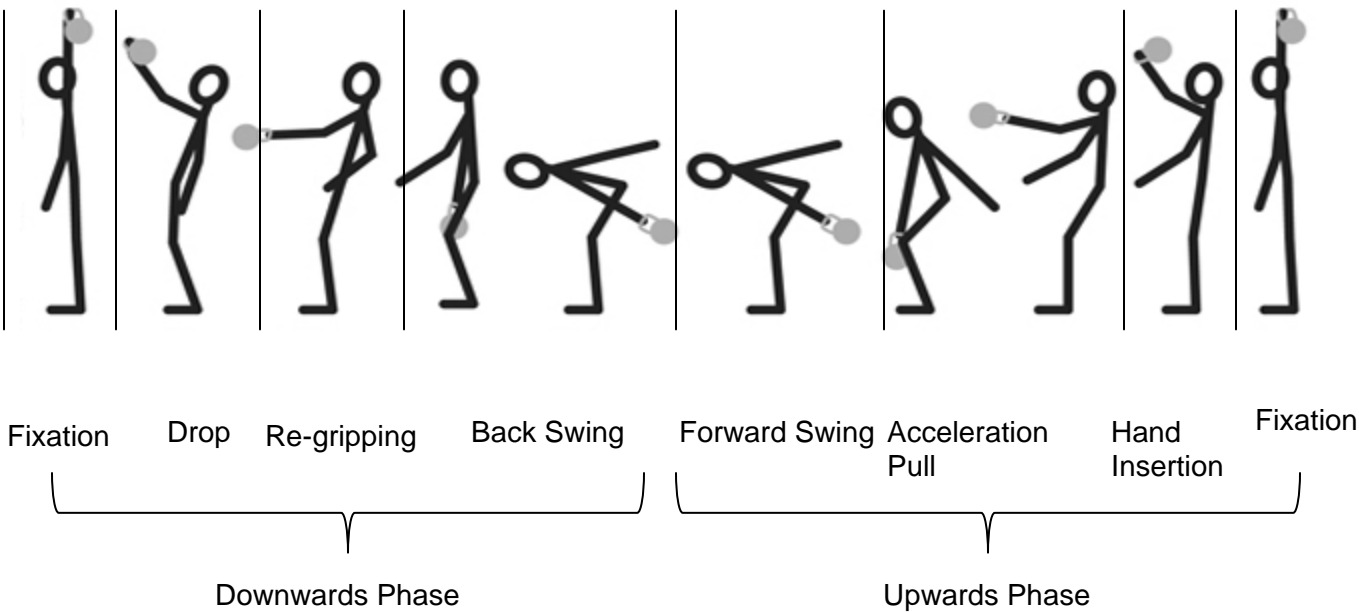


Figure 1. Phases of the kettlebell snatch.

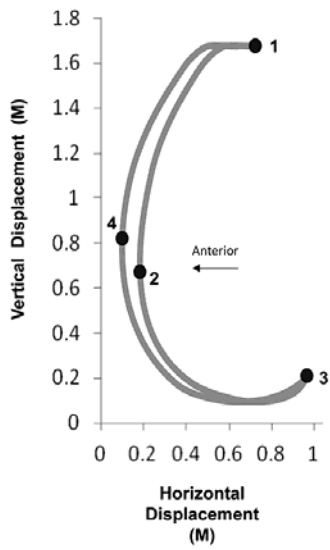


Figure 2. An example of the four points of error in the kettlebell snatch.

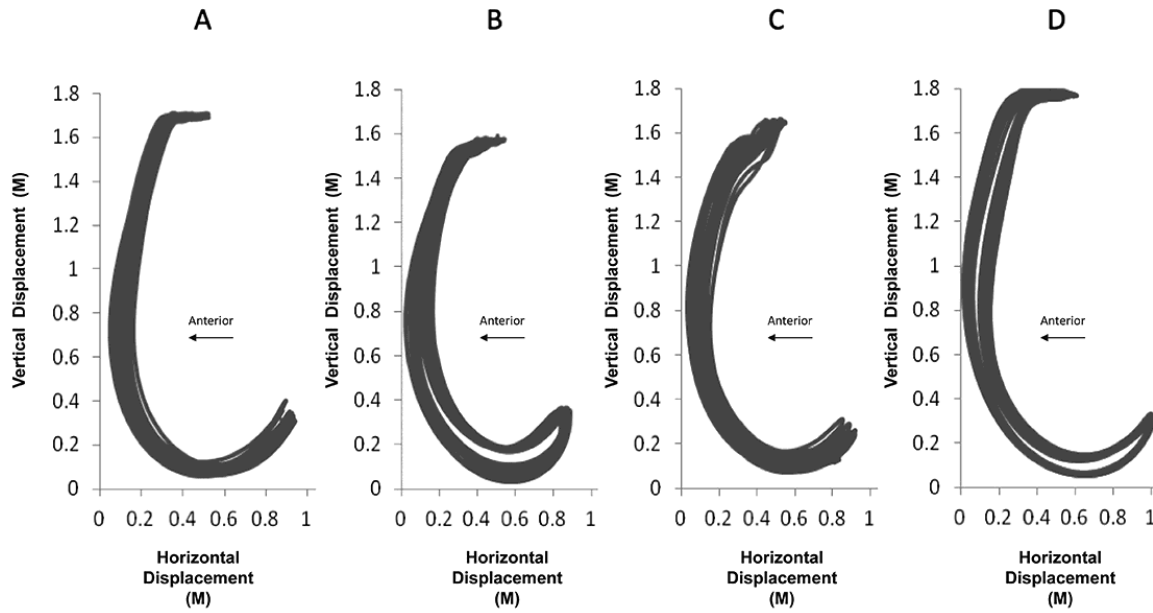


Figure 3. Sagittal plane kettlebell trajectory.

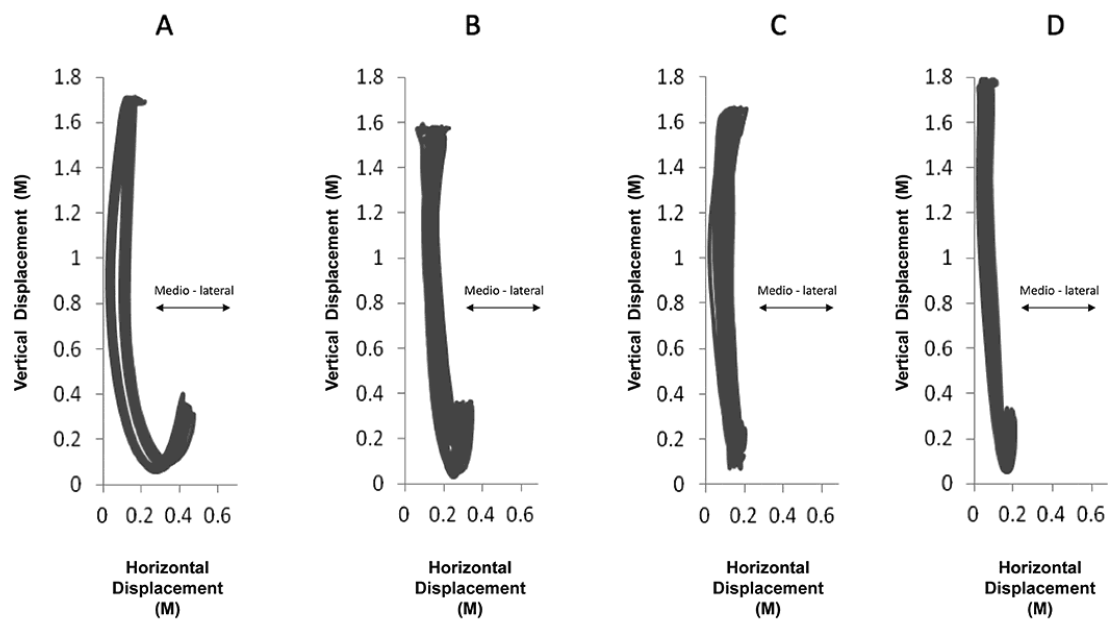


Figure 4. Frontal plane kettlebell trajectory.

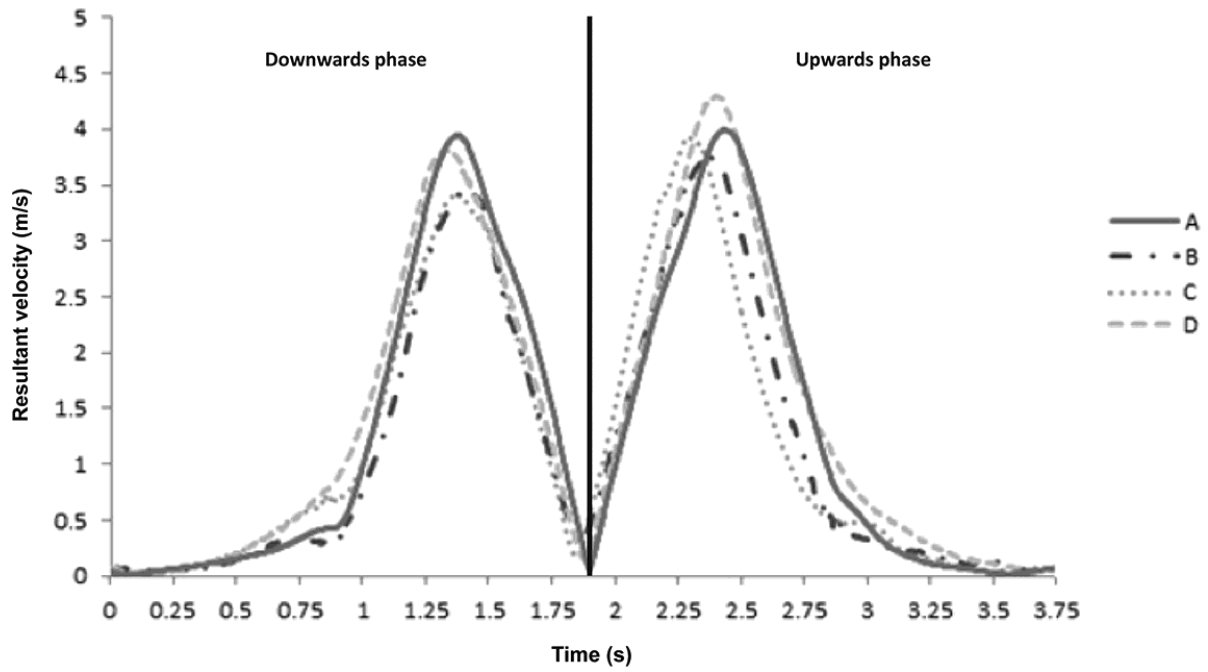


Figure 5. Typical KB resultant velocity-time curve for respective participants.

TABLES

Table 1. Mean displacement ranges (m) and ratios for respective participants

	Lifter A		Lifter B		Lifter C		Lifter D	
	Up Phase	Down Phase	Up Phase	Down Phase	Up Phase	Down Phase	Up Phase	Down Phase
APV	0.67 ± 0.02	0.63 ± 0.03	0.66 ± 0.02	0.60 ± 0.02	0.60 ± 0.02	0.56 ± 0.02	0.66 ± 0.02	0.60 ± 0.02
MLR	0.31 ± 0.01	0.26 ± 0.02	0.13 ± 0.03	0.13 ± 0.03	0.05 ± 0.02	0.06 ± 0.02	0.08 ± 0.02	0.07 ± 0.02
Vertical	1.265 ± 0.024	1.265 ± 0.024	1.240 ± 0.020	1.240 ± 0.020	1.393 ± 0.016	1.393 ± 0.016	1.466 ± 0.020	1.466 ± 0.020
AP	0.845 ± 0.014	0.798 ± 0.027	0.820 ± 0.016	0.744 ± 0.025	0.834 ± 0.024	0.783 ± 0.035	0.967 ± 0.014	0.877 ± 0.014
ML	0.394 ± 0.018	0.329 ± 0.031	0.166 ± 0.036	0.165 ± 0.34	0.065 ± 0.026	0.080 ± 0.035	0.113 ± 0.015	0.103 ± 0.015

All data are mean±standard deviations. APV: Anterior-Posterior to Vertical ratio, MLV: Medio-lateral to Vertical ratio.

Table 2. Three dimensional ranges and effect size between the midpoint of the upwards and downwards phases (m).

	Lifter A	Lifter B	Lifter C	Lifter D
AP	0.049 ± 0.023**	0.076 ± 0.029**	0.046 ± 0.026**	0.090 ± 0.017**
ES	1.99	4.19	2.06	6.67
ML	0.070 ± 0.020**	0.018 ± 0.013	0.035 ± 0.022	0.014 ± 0.008*
ES	3.30	0.06	0.61	0.59
Vertical	0.022 ± 0.015**	0.062 ± 0.030**	0.034 ± 0.020	0.094 ± 0.028**
ES	1.29	3.45	0.51	5.34

All data are mean + standard deviations. AP: Anterior-posterior, ML: Medio-lateral,

*Significant difference in positions of upwards and downwards phases ($p < 0.05$),

** Significant difference in positions of upwards and downwards phases ($p < 0.01$).

Table 3. Mean resultant velocity (m.s⁻¹) of respective participants.

Phase	Lifter A	Lifter B	Lifter C	Lifter D
Upwards	3.95 ± 0.4	3.88 ± 0.03	4.03 ± 0.13	4.27 ± 0.04
Downwards	4.00 ± 0.04	3.52 ± 0.05	3.39 ± 0.09	3.83 ± 0.02
ES	-1.19**	7.45**	3.21**	12.05**

All data are mean + standard deviations.

** Significant difference in resultant velocity of upwards and downwards phases ($p < 0.01$).

Table 3. Displacement range, radial error and absolute error for respective participants (m)

	Lifter A	Lifter B	Lifter C	Lifter D
Phase	Anterior-Posterior			
End Back Swing				
Range	0.054 ± 0.015	0.033 ± 0.012	0.072 ± 0.024	0.044 ± 0.012
AE	0.012 ± 0.09	0.010 ± 0.04	0.019 ± 0.013	0.010 ± 0.007
RE (APV)	0.023 ± 0.016	0.023 ± 0.09	0.024 ± 0.013	0.019 ± 0.012
Acceleration				
Pull				
Range	0.032 ± 0.009	0.058 ± 0.014	0.066 ± 0.023	0.050 ± 0.011
AE	0.008 ± 0.005	0.010 ± 0.010	0.019 ± 0.013	0.008 ± 0.008
RE (APV)	0.015 ± 0.008	0.017 ± 0.012	0.028 ± 0.014	0.015 ± 0.012
Fixation				
Range	0.039 ± 0.010	0.105 ± 0.028	0.094 ± 0.028	0.067 ± 0.021
AE	0.007 ± 0.006	0.022 ± 0.015	0.022 ± 0.017	0.018 ± 0.010
RE (APV)	0.008 ± 0.006	0.023 ± 0.016	0.023 ± 0.016	0.018 ± 0.010
Re-gripping				
Range	0.105 ± 0.026	0.069 ± 0.020	0.090 ± 0.023	0.050 ± 0.015
AE	0.016 ± 0.008	0.016 ± 0.011	0.017 ± 0.015	0.011 ± 0.008
RE (APV)	0.022 ± 0.020	0.024 ± 0.011	0.032 ± 0.027	0.021 ± 0.009
Phase	Medio-Lateral			
End Back Swing				
Range	0.062 ± 0.016	0.078 ± 0.024	0.051 ± 0.018	0.031 ± 0.009
AE	0.013 ± 0.010	0.019 ± 0.014	0.016 ± 0.007	0.007 ± 0.005
RE (MLV)	0.023 ± 0.016	0.023 ± 0.009	0.024 ± 0.013	0.019 ± 0.012
Acceleration				
Pull				
Range	0.051 ± 0.017	0.062 ± 0.016	0.056 ± 0.015	0.046 ± 0.012
AE	0.015 ± 0.008	0.015 ± 0.009	0.011 ± 0.009	0.008 ± 0.009
RE (MLV)	0.015 ± 0.008	0.017 ± 0.012	0.028 ± 0.014	0.015 ± 0.012
Fixation				
Range	0.062 ± 0.020	0.105 ± 0.026	0.090 ± 0.025	0.044 ± 0.014
AE	0.018 ± 0.009	0.019 ± 0.017	0.019 ± 0.016	0.012 ± 0.008
RE (MLV)	0.018 ± 0.008	0.020 ± 0.016	0.020 ± 0.015	0.012 ± 0.007
Re-gripping				
Range	0.097 ± 0.027	0.073 ± 0.018	0.108 ± 0.030	0.069 ± 0.019
AE	0.021 ± 0.015	0.014 ± 0.012	0.024 ± 0.013	0.015 ± 0.011
RE (MLV)	0.025 ± 0.017	0.023 ± 0.012	0.037 ± 0.027	0.023 ± 0.009
Phase	Vertical			
End Back Swing	0.093 ± 0.024	0.077 ± 0.022	0.058 ± 0.016	0.074 ± 0.020

Range	0.018 ± 0.015	0.019 ± 0.009	0.012 ± 0.009	0.015 ± 0.011
AE				
Acceleration				
Pull				
Range	0.044 ± 0.014	0.058 ± 0.016	0.069 ± 0.022	0.061 ± 0.016
AE	0.012 ± 0.007	0.011 ± 0.008	0.018 ± 0.011	0.012 ± 0.011
Fixation				
Range	0.004 ± 0.001	0.018 ± 0.005	0.019 ± 0.005	0.012 ± 0.004
AE	0.001 ± 0.001	0.004 ± 0.003	0.004 ± 0.003	0.003 ± 0.002
Re-gripping				
Range	0.055 ± 0.017	0.071 ± 0.019	0.144 ± 0.036	0.055 ± 0.018
AE	0.012 ± 0.008	0.015 ± 0.007	0.025 ± 0.024	0.015 ± 0.009

All data are mean ± SD, unless otherwise stated. AE: absolute error. RE: radial error
APV: Anterior-Posterior to Vertical ratio, MLV: Medio-lateral to Vertical ratio.